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LABORATORY TENSILE TESTING OF UNMEASURABLE PARTS OF REINFORCING BARS JOINED BY BUTT WELDING METHOD

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ABSTRACT: The objective of the study is to test the joints of waste reinforcing bar and steel wires for tension. The tests conducted within the conditions of construction enterprises of the Republic of Kazakhstan (RK) showed that, depending on the arrangement of production and the productivity of the production of reinforced concrete products, more than 2% of reinforcing steel is wasted. The authors are developing a technology for the efficient use of the waste reinforcing bar and steel wires in the production of reinforced concrete products. This article presents the results of a laboratory test of joining reinforcing bar waste and steel wires for tension. Experimental studies were carried out on the flash butt machine MSR-25 within the conditions of the laboratory base of the Kazakhstan Institute of Welding of the Karaganda Technical University (KTU). Samples were tested in the engineering laboratory of Karaganda Technical University. As a result of the test, it was found that the rods joined from several waste reinforcing bars and steel wires by the method of flash butt welding, having 2-3 joints each, withstand a load in the range of 25000 ÷ 40000 N. The test results showed sufficient strength of the welded joints.

Keywords: Reinforced concrete products, Reinforcing bar, Steel wires, Flash butt welding, Tensile testing

1. INTRODUCTION

Reinforcing bar accounts for about 20% of the cost of reinforced concrete products in factory production, therefore, the arrangement of reinforcement works at prefabricated reinforced concrete plants is important in terms of technics and economy.

Construction plants of the RK when it comes to producing reinforced concrete products manufacture items that are indispensable in the conditions of modern construction: various types of concrete and mortar, as well as a wide range of reinforced concrete products used in all types of construction. These are road slabs, curb stone, paving slabs, foundation blocks, fence sections, piles, road slabs, airfield slabs, foundation blocks, shield supports, trays, elevator shafts, well rings, ventilation blocks, flights of stairs, and lintels.

The production of reinforced concrete products has a complex technological cycle and requires careful fulfillment of technological requirements at each stage of the process. Any structure made of reinforced concrete has two components - concrete and reinforcing bar [1]. Depending on the function of the products, concrete of various qualities can be used in their manufacture, meeting the requirements of strength and reliability. Concrete of the highest quality is used for foundation blocks and piles, which must withstand significant loads. Cheaper types of concrete are used for fence sections and other products that are not exposed to significant loads during operation. The reinforcing bar is located inside the reinforced concrete and is an inconspicuous, but very important part of the structure. The reinforcing bar reinforces the product, gives it shape, and makes it suitable for use in various types of construction. When it comes to the strength of the entire structure, the supporting frame, the internal skeleton, plays a significant role. The reliability, resistance of reinforced concrete products to all types of mechanical impacts, and loads of different intensity largely depend on the reinforcing frame [2].

The results of the study [3] were carried out in the conditions of the construction plants of the RK, in particular in the conditions of Powerbeton LLP (Prishakhtinsk city) [4], NORD Prom NS LLP (Temirtau city), ZhBI-5 LLP (Aktas city), Remstroytekhnika JSC (Almaty city), Temirbeton - 1 LLP (Almaty city) [5], showed that, depending on the arrangement of production and on the productivity of the production of reinforced concrete products, about 2% of reinforcing steel is wasted [2]. Figure 1 shows a histogram of the percentage of waste reinforcing bars at a construction enterprise.

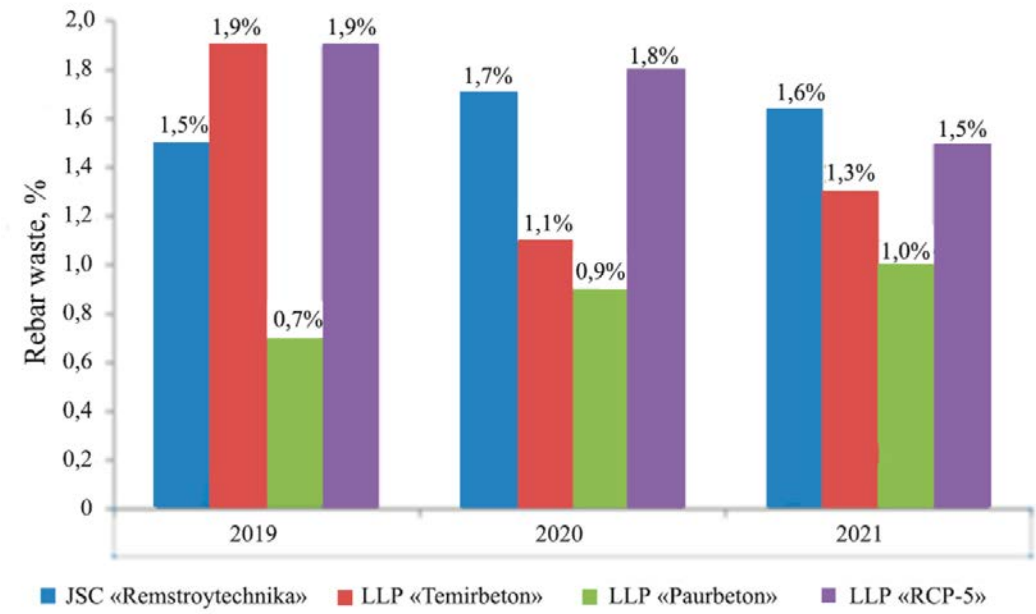


Fig.1 The percentage of waste reinforcing bars

As of today, the domestic industry of building materials can satisfy only a part of the needs of the construction complex of the RK, and as a result, imported products occupy a significant share in the market, preventing a shortage of almost all types of building materials. Even though in recent years production of ceramic tiles, plastic pipes, metal tiles, plastic joinery, dry mixes, and other products has been put into operation in the RK, almost all products of the building materials industry in Kazakhstan are uncompetitive in the foreign market.

Another of the most important tasks of the modern construction industry is the development and implementation of resource-saving technologies that ensure the widespread use of industrial waste and local natural materials, enabling the rational use of raw materials and fuel and energy resources. The optimal solution to the problem lies in the development and implementation of low-waste technologies in production.

To effectively use waste reinforcing bars, bars, and wires in the manufacture of reinforced concrete products, it was recommended to solve several main problems in the reference [4], one of which is a welded method of joining unmeasurable reinforcing waste in the conditions of construction enterprises.

In paper [6], the possibility of using high-strength steel bars in longitudinal and transverse reinforcement of reinforced concrete beams was investigated. Test results of beams with high-strength reinforcing steel bars showed that they can maintain deformation and loading capacity under monotonic loads. Tests on specimens under monotonic load were carried out on a universal testing machine. The work proves that high-strength steel bars can be used in the manufacture of reinforced concrete products.

In works [7,8] there is information about tensile testing of welded joints of titanium alloys using specimens having a cylindrical shape of a working section. At the same time, failure of the specimens occurred along the base metal, away from the weld and the zone of thermomechanical influence.

In work [9] the results of the development of a high-strength concrete mixture for manufacturing reinforced concrete products, in particular, bar lintels are given. The frames of these lintels are made of welded reinforcing bars connected to non-dimensional pieces [10]. The use of a high-strength concrete mix increases the strength of the lintel blocks.

Two welding methods are proposed for joining unmeasurable reinforcing wastes – flash butt welding and friction welding. In this paper, we examine the strength of joints of unmeasurable reinforcing sections by the flash butt welding method. To do this, we do tensile testing of samples of reinforcing bars joined by flash butt welding.

2. RESEARCH METHODOLOGY AND EQUIPMENT USED

The relevant task is to determine a resource-saving welding method for joining unmeasurable reinforcing waste in the conditions of construction enterprises of the RK.

The research methodology is based on such sciences as reinforced concrete manufacturing technology, welding technologies and equipment, and the theory of welding processes. Unmeasurable reinforcing bars were joined by the flash butt welding method in the laboratory of the International Welding Institute under Karaganda Technical University. To test the samples, the equipment of the testing laboratory of the engineering profile Integrated Development of Mineral Resources of KTU was used.

Unmeasurable reinforcing bars were joined by the flash butt welding method on a flash butt machine MSR-25. Its advantage is that it does not need to create a large voltage on the welding electrodes to ignite and maintain the high-temperature plasma of the welding arc. This is because the process of conventional resistance welding itself occurs as a result of local melting of the metal at the point of direct contact of the electrodes with the surface of the workpiece, i.e. in the place of closure of the electrodes or with a difference in butt welding in the contact of the welded surfaces of the ends of the workpieces, i.e., butt too but [11].

Figure 2 shows unmeasurable reinforcing bars prepared for welding, the flash butt machine MSR-25, and its technological scheme of welding.

a) *b)* *c)*

a - unmeasurable reinforcing bars; *b* - flash butt machine MSR-25; *c* - technological scheme of welding

Fig.2 Unmeasurable reinforcing bars, flash butt machine MSR-25 and its technological scheme of welding

Butt welding is a method of electric resistance welding when parts are joined over the entire area of contact (over the entire cross-section). The parts (see Fig. 2, *c*) are fixed with a clamping force F_{clamp} in current-carrying clamps 2, and 4, one of which, for example, clamp 4, is movable and is connected to the drive of the compression force F_{comp} of the machine. Flash butt welding is the process when the parts are first supplied with voltage from the welding current source (PS) 3, and then they are brought together. When the parts come into contact at separate points (due to surface irregularities), due to the high current density, the metal at the contact point quickly heats up with the formation of liquid bridges, which then explode. The heating of the ends of the parts occurs because of their melting as a result of the continuous formation and destruction of multiple contacts - jumpers. By the end of the process, a continuous layer of liquid metal is formed at the ends. At this moment, the speed of ends joining and parts settling increases; the ends are closed, and most of the liquid metal, together with surface films and part of the solid metal, is squeezed out of the welding zone, forming a thickening - burr 5 (see Fig. 2, *c*). The welding current is switched off automatically during parts settling. Before welding, we clean and align joined ends. Using a brush for metal, we clean the surface to a shine. When butt welding samples of reinforcing bars, we will control the coaxiality of the bar so that it is fixed stably. Displacement tolerance is not more than 0.05% of the rod diameter.

Figure 3 shows samples of reinforcing bars joined by flash butt welding.

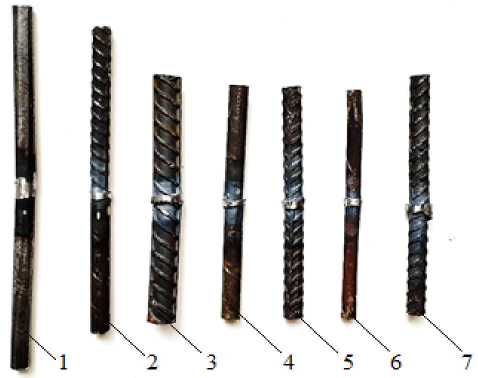


Fig.3 Samples of reinforcing bars joined by flash butt welding.

Samples were tested on the INSTRON 5980 electromechanical testing machine.

Figure 4 shows the INSTRON 5980 electromechanical testing machine.

Fig.4 INSTRON 5980 electromechanical testing machine

For tensile testing, samples of round and periodic profile reinforcing bars with an untreated surface with a nominal diameter of 8 to 12 mm were used. The shape, dimensions, and requirements for processing the working part of the samples by GOST (State Standard) 1497-84. The total length of the rebar sample is selected depending on the working length of the sample and the grip design of the testing machine. The working length of the sample must be at least 200 mm by GOST (State Standard) 12004-81. The initial calculated length for samples of reinforcing bar and wire should be determined by the regulatory and technical documentation for the finished product.

The initial cross-sectional area of the raw samples of the reinforcing bar of a periodic profile F_o, mm^2, is calculated by the formula

$$F_0 = \frac{m}{\rho l} \quad (1)$$

where m – a mass of test sample, kg;

l - testing sample length, m;

p - steel density, 7850 kg/m^3.

For turned and round samples of reinforcing bar with a nominal diameter of 3.0 to 40.0 mm, the cross-sectional area is determined by measuring the diameter along the length of the sample in three sections: in the middle and at the ends of the working length; in each section in two mutually perpendicular directions. The cross-sectional area of the sample is calculated as the arithmetic mean of these six measurements. The diameters of round and turned samples of reinforcing bar with a nominal diameter of 3.0 to 40.0 mm are measured with a caliper by GOST (State Standard) 166-89 or a micrometer by GOST (State Standard) 6507-90.

The mass of tested samples of rebar of a periodic profile with a nominal diameter of less than 10 mm is determined with an error of not more than 1.0g, samples of rebar with a diameter of 10 to 20 mm - with an error of not more than 2.0g. Samples of reinforcing steel are weighed on a scale by GOST (State Standard) 29329-92, and the length of the sample is measured with a metal ruler by GOST (State Standard) 427-75.

During testing, the following requirements must be met:

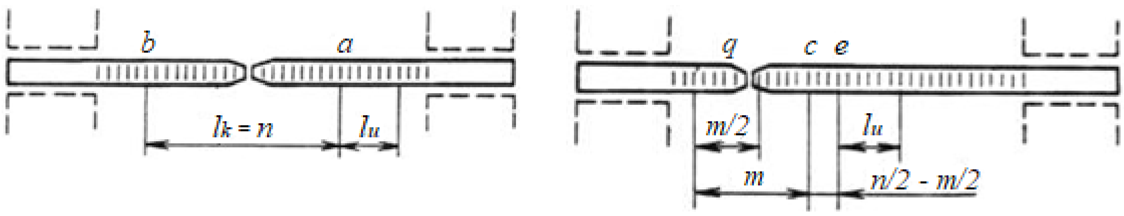
- reliable centering of the sample;
- the smoothness of loading;
- the average loading rate during testing to the yield point should not be more than 10 MPa (1 kgf/mm^2) per second; beyond the yield point, the loading rate can be increased so that the speed of movement of the movable grip of the machine does not exceed 0.1 of the working length of the test sample per minute; the scale of the force meter of the testing machine should not exceed five times the expected value of the maximum load P for the tested sample of rebar;
- the design of the grips of the testing machine should exclude the possibility of turning the ends of the rope around the axis of the sample.

The final estimated length of the sample $l_к$, including the place of its tension, is determined in the following way.

Before testing, the sample at a length greater than the working length of the sample is marked into n equal parts using marks applied by a dividing machine, brackets, or a core. The distance between the marks for the reinforcing bar with a diameter of 10 mm or more should not exceed the value of d and be a multiple of 10 mm. For the reinforcing bar with a diameter of less than 10 mm, the distance between the marks is assumed to be 10 mm. When marking samples, it is allowed to take the distance between the marks more than 10 mm and exceed the value of d, but not more than the value of the initially estimated length l_0.

If the number of intervals n matching the initial length of the sample turns out to be fractional, it is rounded up to the nearest integer. After the test, the parts of the sample are carefully placed together in a straight line. From the place of the gap in one direction, $n/2$ intervals are laid off and a mark is placed. If the value $n/2$ turns out to be fractional, then it is rounded up to the nearest whole number. The segment from the tension point to the first mark is considered as a whole interval.

Figure 5 shows the schemes for determining the final calculated length of the sample.



a) b)

a – when the tension point is in the middle; *b* – when the tension point is closer to the edge of the machine grip

Fig.5 Schemes for determining the final calculated length of the sample

From mark, *a*, *n* intervals are set to the tension point and mark *b* is placed (see Fig. 5, *a*). The segment *ab* is equal to the final calculated length $l_к$ obtained at the tension point. If the tension point is closer to the edge of the grip of the machine than the value *n/2* (see Fig. 5, *b*), then the final calculated length $l_к$ obtained after the tension is determined as follows: from the tension point to the *q* end mark at the grip, the number of intervals is determined, which is marked as *m/2*. From the *q* point to the tension point, *m* intervals are set and the *c* mark is put. Then, *n/2-m/2* intervals are set from the *c* mark and the *e* mark is put.

The final sample length $l_к$, mm, is calculated by the formula

$$\boldsymbol{l_k = cq + 2ce} \tag{2}$$

where *cq* and *ce* - respectively, the length of the sample section between the points *c-q* and *c-e*.

If the tension point is at a distance from the grip less than the length of two intervals or $0.3l_0$ for samples with a diameter of less than 10 mm, the calculated length cannot be reliably determined and a second test is carried out.

Relative equal elongation δ_p is determined in all cases outside the tension area at the initial calculated length equal to 50 or 100 mm. In this case, the distance from the tension point to the nearest mark of the initial calculated length for a reinforcing bar with a diameter of 10 mm or more should not be less than 3*d* and more than 5*d*, and for a reinforcing bar with a diameter of less than 10 mm - from 30 to 50 mm.

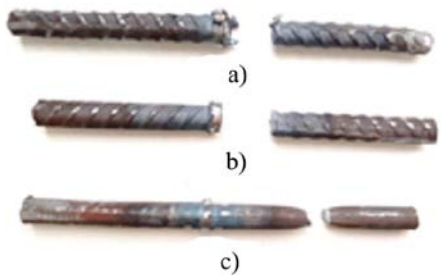
To calculate the strength of welded butt joints the methodology given in the code [12] was used.

3. LABORATORY TESTING OF SAMPLES

Tensile testing of samples was conducted on an INSTRON 5980 electromechanical testing machine. Figure 6 shows the testing process.

Fig.6 Tensile testing process

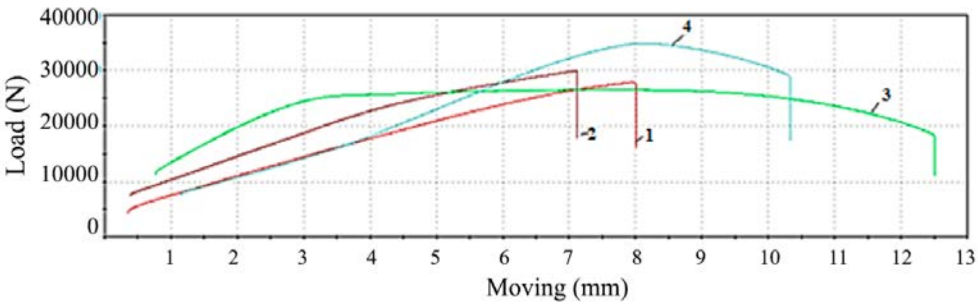
Figure 7 shows some samples after tensile testing.



a – Ø10 mm; *b* – Ø8 mm; *c* – Ø6 mm

Fig.7 Some samples after tensile testing

The results of the test were processed on a computer and a tensile diagram of the samples was created. Figure 8 shows the tensile diagram of the samples.



1,2,3,4- samples

Fig.8 Tensile diagram of samples

Tensile testing of welded samples was carried out until the materials were destroyed. A comparison of the results on yield stresses shows that sample number 4 is more likely prone to resistance to an external load. The remaining samples' strength characteristics are lower. The tensile diagrams of samples No. 1 and No. 2 are similar to the work of brittle materials. This is also confirmed by the final result of the samples, that is, the destruction occurs near the weld. In sample No. 3, the plastic properties of the material are excellent and satisfactory, which is confirmed by the horizontal section.

The calculation of butt welded joints is carried out according to the method described in [12].

The tensile strength of butt joints is calculated using the formula:

$$\frac{N}{tl_W} \leq R_{wy}\gamma_c \quad (3)$$

where N - the maximum tensile load acting on the connection;

t - the smallest thickness of the elements to be joined;

l_w - design length of the weld;

R_{wy} - design resistance of butt welded joints to the yield strength;

γ_c - factor of working conditions.

To calculate, we select the worst-case version of a welded joint, i.e. the sample (Fig. 7, a) where the tear occurred as close to the weld as possible.

We determine the data for calculation, in our case the maximum tensile load N = 40000 N, the smallest thickness of the connected armature t = 10 mm, the calculated length of the welded seam makes l_w = 19 mm, the value of design resistance of butt welded connections to the yield point we choose according to recommendations [12, table 4] R_{wy} = 235 MPa. Substituting the value in eq. (3), we obtain:

$$\frac{40000}{10 * 19} \leq 235 * 0,95$$

$$210,5 \leq 223,25$$

Tensile strength conditions at the butt joint are thus fulfilled.

4. CONCLUSION

1. Research conducted within the conditions of construction enterprises of the RK showed that, depending on the arrangement of production and on the productivity of the production of reinforced concrete products, more than 2% of reinforcing steel is wasted.

2. As a result of the test, it was found that the rods joined from several waste reinforcing bars and steel wires by the flash butt welding method, having 2-3 joints each, withstand a load in the range of 25000 ÷ 40000 N. The test results showed sufficient strength of the welded joints.

3. The test results were also confirmed by calculation, and the strength conditions of the butt welds were maintained.

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